Assessment of Structural Behaviour of MAPP-1 Containment from Pressure Test

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Abstract

The paper describes in detail the experimental investigation carried out during the pressure test of containment-1 of the Madras Atomic Power Project (MAPP-1) and also processing and interpretation of test results for assessing the structural behaviour of the containment. Moreover, a comparison of the analytical results of strains and deflections of the containment with the experimental values for pressure and diurnal thermal effects is also presented.

The MAPP-1 containment is a prestressed concrete structure in the form of a vertical cylindrical shell with a domic roof. It houses a 200 MW(e) CANDU type of reactor and it was originally designed for an internal pressure of 16.5 psig under maximum credible accident (MCA) condition.

The paper describes the instrumentation adopted for measurement of deflections, strains, and temperatures. Measurements were carried out not only during pressure tests but also when the containment was not pressurised ('dummy runs'). The dummy runs were intended for assessing the structural behaviour due to diurnal heating alone. After a detailed analysis of measurements, it was observed that the pattern of temperature distribution at various locations (on top and bottom surfaces) in the dome can be reasonably estimated from the data available by knowing the temperature at a single reference location at a given time of the day. Moreover, a detailed analysis of the measured strains had indicated that they are mainly dependent on temperature gradient between the bottom and top surfaces rather than the average temperature. On the other hand, the deflections are mainly dependent on average temperature of the dome. Based on these observations a simple method of estimating the strains at various locations due to diurnal heating during the pressure tests was evolved.

The paper also presents the analytical results obtained by the finite element analysis for thermal effects. It can be seen from the paper that the simple method adopted for separating the strains due to diurnal heating during the pressure test is sufficiently accurate as borne out by the comparison with analytical results obtained by the finite element technique.

1. Introduction

Nuclear containments are required to be tested before commissioning of reactors by subjecting them, generally, to an internal pressure of 1.15 x design pressure which is based on loss of coolant accident analysis. The new ASME Section III, Division 2, Code for reactor vessels and containments specifies such a proof test. Leak-tightness and structural integrity of the containment can be evaluated by making necessary measurements during the test and analysing the test data.

The report presented herein describes the experimental investigations carried out during the pressure test of containment-1 of the Madras Atomic Power Project (MAPP) for assessment of its structural behaviour. The paper also presents strains and deflections of the containment for pressure and diurnal thermal effects derived from test data and their comparison with analytical values.

2. Description of the Containment and Instrumentation

2.1 Containment

MAPP-1 containment is a prestressed concrete vessel in the form of a vertical circular cylinder covered with a domic roof (Refer to Fig.1). A masonry wall is provided surrounding the prestressed concrete perimeter wall to make the cylindrical portion a double containment. It houses a 235 MW(e) CANDU type of reactor and it was designed for an original accident pressure of 16.5 psig (0.1137 N/mm^2) for which the design pressure was 20.6 psig (0.1419 N/mm^2) under maximum credible accident (MCA) condition.

2.2 Instrumentation

The purpose of the instrumentation was to measure the structural response of the containment during the proof test. Deflections, strains, and temperatures were measured at different locations shown in Fig.2. Measurement of temperature provided the requisite information on deflections and strains due to diurnal thermal effects during the test and thereby evaluate the structural response of the containment due to pressure alone.

2.2.1 Deflection

Three types of deflection measuring devices were used. For the radial and vertical deflections of the perimeter wall deflectometers with least counts of 0.01 mm and 0.001 mm were used. These dial gauges were fixed on mild steel angles which were embedded in the rubble masonry wall around the perimeter wall of the containment. The rubble wall is structurally independent of the perimeter wall and its radial movement due to normal wind and temperature were observed to be negligible during a preliminary investigation.

For measuring deflections of the dome, two WILD T2 theodolites with a least count of 1 second for angular measurement, were used. The theodolites were positioned on the roof of the adjoining building.

In order to verify the deflections obtained from observations made by theodolites, strain gauge based displacement transducers were employed at two important locations, viz., the crown and the haunch point of the dome. These transducers were mounted on steel towers, which were erected inside, independent of the containment and were connected to a 100-channel digital data logger.

2.2.2 Strain

Electrical resistance strain gauges of 70 mm length were used to measure the strains in the dome and haunch portions of the containment. These phester-backed (phenol-epoxy) uniaxial and self-temperature compensated (for concrete) gauges were pasted, using the matching epoxy cement, at 16 locations, eight each on inside and outside of the containment. The strain gauges were pasted and water-proofed with considerable care so that the performance of the strain gauges would not be affected by the environment over the duration of a few months. Multi-cored twisted and shielded cables were used to connect strain gauges to the 100-channel digital data logger for strain measurement.

2.2.3 Temperature

A total of nine thermisters were installed in the dome to measure the temperature of outer and inner surfaces of concrete. The thermisters were potted in copper tubes. The terminals of the thermisters were connected to a digital multimeter using the same type of lead wires as that were used for electrical strain gauges.

3. Pressure Test and Measurement

In all four cycles of pressure testing were carried out during the period June-August 1979. The containment was subjected to a maximum pressure of 13.08 psig (0.0918 N/mm^2) during one of the cycles of testing. Variation of pressure with time for this cycle is shown in Fig.3.

Strains, deflections, and temperatures were measured during the pressure test of the containment. Effects due to diurnal variations in temperature would be reflected in these measurements [1]. It was necessary to apply suitable correction to the test data so as to obtain response of the containment due to pressure alone. In order to assess the correction needed, response of the containment was also measured for about two days at a time either immediately before or after the pressure test. These observations were termed as "Dummy runs".

4. Analysis of Test Data and Results

The aims of the analysis were (i) to assess structural response of the containment separately for the internal pressure loading and the diurnal thermal effects, and (ii) to determine whether the response due to pressure loading is linear over the range of pressure loading.

As the perimeter wall of the containment was shielded against solar radiation by the masonry wall, its response to internal pressure could be directly evaluated from test results. Fig.4 shows the deflection of the wall measured along one of the meridians at different stages of internal pressure loading.

Unlike in the case of perimeter wall, suitable corrections had to be applied to the test data to arrive at the response of the dome due to internal pressure only. The corrections to be applied had to be derived from the data on distribution and variation of temperatures and the response of the containment during the dummy runs. Typical observations in this regard are presented in Figs.5 and 6. After a detailed analysis of all the data obtained, the following general observations could be made:

- variations in temperature at different locations were similar and, therefore, the variation at any point could be approximately related to that of a chosen "reference point".
- deflection of the dome followed the pattern of variation of average of inside and outside temperatures at the reference point but with definite time lag.
- strains closely followed the pattern of variation of temperature difference between

outside and inside surfaces of the dome (Refer Fig.6). Strains mainly depend on temperature differences.

Suitable corrections were worked out for deflections and strains of the dome, by making use of the above observations, for arriving at the response for internal pressure alone. Figs.7 and 8 show the variations of deflection and strain with pressure respectively.

5. Theoretical Analyses and Comparison of Results

A 1/12 scale microconcrete model of the MAPP-1 containment tested earlier[2] for internal pressure was analysed by using the finite element method [3]. The modulus of elasticity of microconcrete used in the analysis was determined by conducting a test on the model and Poisson's ratio was assumed to be 0.17. Comparison of deflections and strains obtained theoretically and those obtained from the test is shown in Figs.7 and 9 respectively.

The dome of the containment was also analysed for thermal effects by using the finite element method by applying the temperature differences observed during a dummy run. It was also analysed for uniform temperature difference throughout the dome. These analytical studies were carried out assuming the springing of the dome to be fixed. The computed values of strain per degree difference in temperature at the crown was found to be about 8 μ in both the cases. Fig.10 shows the values of strain at the crown of the dome derived from test results. This gives a value of 9 μ as the maximum strain per degree difference in temperature. This compares well with the result obtained by the simple analytical model.

6. Conclusions and Remarks

The following conclusions can be drawn from the test results and also their comparison with the values obtained by theoretical investigation:

(i) The deflection and strain response of the dome and that of the perimeter wall of the containment is practically linear with internal pressure.

(ii) Containment seems to have experienced a rigid body movement/tilt and the deflection of the perimeter wall is not axisymmetric (Refer Figs.7 and 9).

(iii) Deflections and strains of the crown of the dome due to internal pressure agree well with the values predicted by theoretical analysis and also with the corresponding values obtained from the model test.

(iv) Both theoretical and experimental results show that diurnal temperature variations cause mainly bending stresses/strains in the dome. Maximum strain was found to be about 9 μ per degree difference in temperature between inside and outside surfaces of dome.

7. Acknowledgement

The experimental investigation presented was sponsored by the Power Projects Engineering Division of the Department of Atomic Energy. The encouragement and assistance provided by Shri V.Ramachandran, Chief Engineer of PPED and his colleagues and by Dr.M.Ramaiah, Director, Structural Engineering Research Centre, Madras, are gratefully acknowledged.

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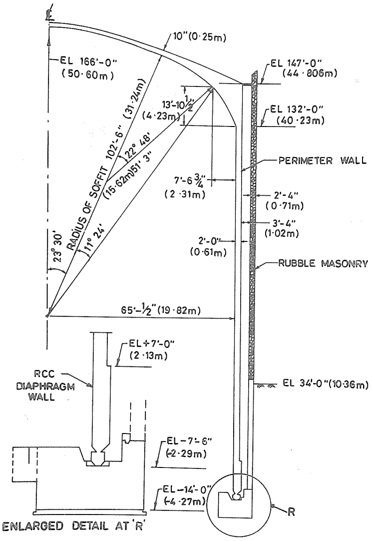

FIG. 1 MAJOR DETAILS OF THE CONTAINMENT

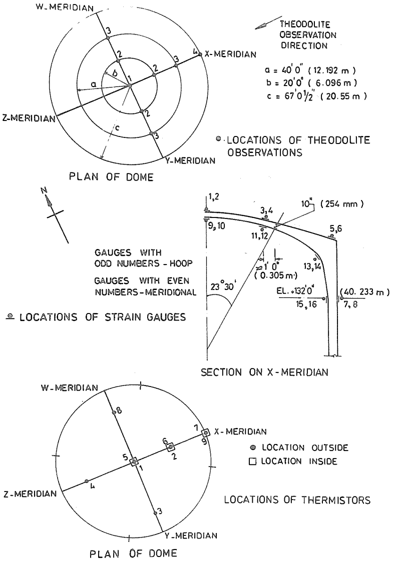

FIG. 2 LOCATIONS OF THEODOLITE TARGETS, STRAIN GAUGES, AND THERMISTERS

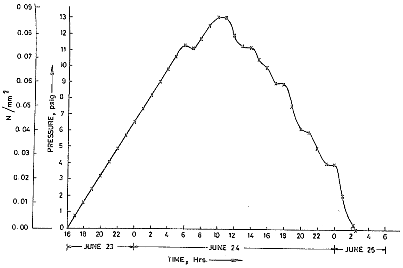

FIG. 3 VARIATION OF PRESSURE WITH TIME DURING PRESSURE TEST

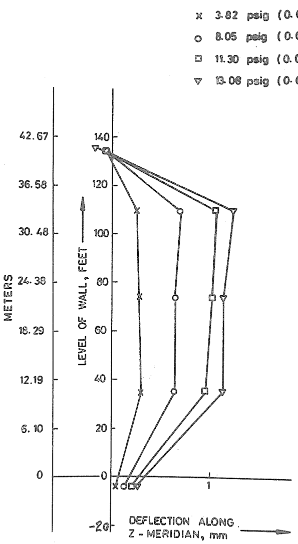

FIG. 4 RADIAL DEFLECTIONS OF PERIMETER WALL DURING PRESSURE TEST

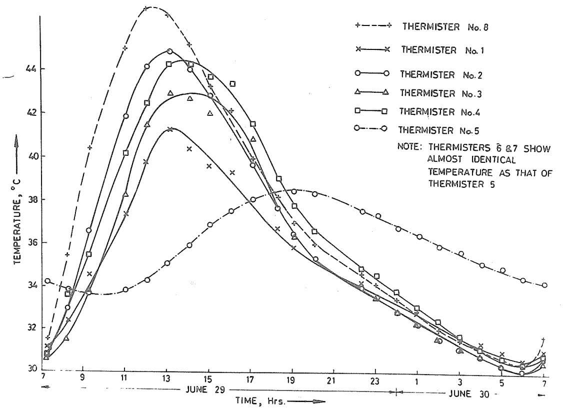

FIG. 5 TEMPERATURE VARIATION DURING DUMMY RUN

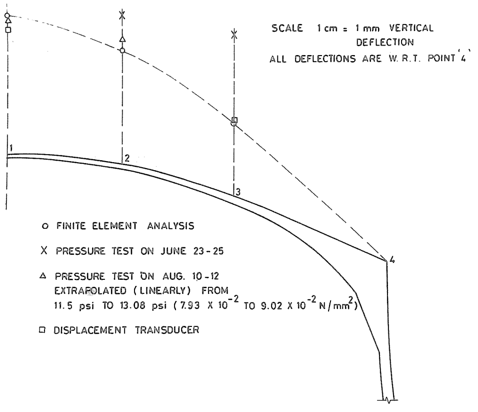

FIG. 6 VARIATIONS OF Ⓐ STRAINS AT DIFFERENT LOCATIONS OF THE DOME AND Ⓑ TEMPERATURE DIFFERENCE DURING DUMMY RUN

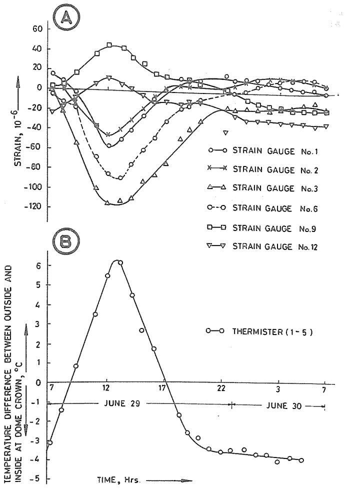

FIG. 7 COMPARISON OF DOME DEFLECTIONS DUE TO PRESSURE

Ⓐ	LEVEL OF PERIMETER WALL		
	-4' (-1.22 m)	74' (22.55 m)	134' (40.88 m)
MAPP-1 CONTAINMENT	-0.04	✱ 2.08 / 1.14	✱ -0.03/-0.16
MODEL	—	✱ 3.43 /-1.77	—
FINITE ELEMENT METHOD	0.01	1.59	-0.13

ALL DEFLECTION VALUES ARE IN mm.

✱ VALUES ON EITHER SIDE OF / INDICATE MEASUREMENTS ON TWO OPPOSITE MERIDIANS

LOCATION / Ⓑ DIRECTION	MAPP-1 PROTOTYPE	MODEL	FINITE ELEMENT METHOD
OUTSIDE			
MERIDIONAL	110	124.88	132
HOOP	106	124.88	132
INSIDE			
MERIDIONAL	134	135.29	150.54
HOOP	126	135.29	150.54

ALL STRAIN VALUES ARE IN 10^{-6}

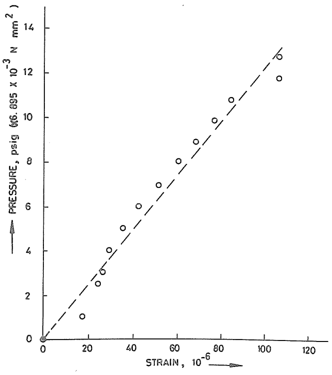

FIG. 8 VARIATION OF STRAIN WITH PRESSURE

FIG. 9 COMPARISON OF EXPERIMENTAL AND THEORETICAL VALUES OF Ⓐ RADIAL DEFLECTIONS OF PERIMETER WALL AND Ⓑ STRAINS AT DOME CROWN

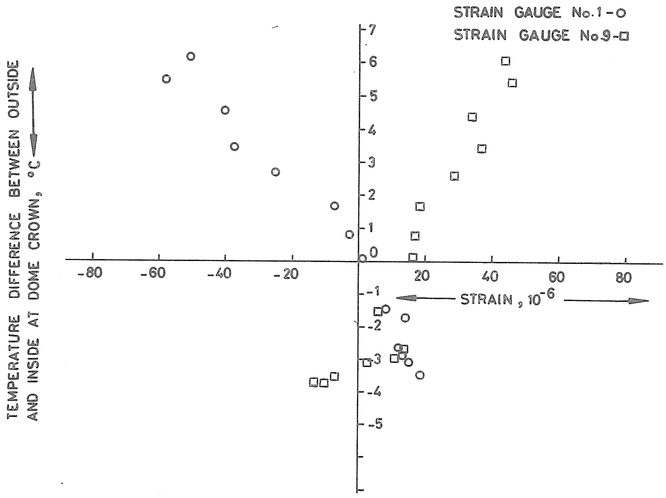

FIG. 10 TEMPERATURE DIFFERENCE VS. STRAIN DURING DUMMY RUN